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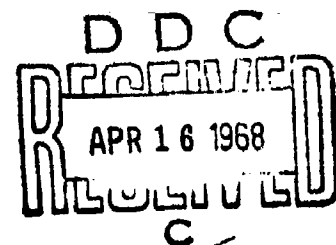


# **FILTERING SYSTEM FOR AEROSPACE WATER RECLAMATION**

**KLAUS FEINDLER**

**AIRCRAFT POROUS MEDIA, INCORPORATED**

**DECEMBER 1967**



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600 - March 1968 - CO455 - 26-571

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**FILTERING SYSTEM  
FOR  
AEROSPACE WATER RECLAMATION**

*KLAUS FEINDLER*

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## FOREWORD

This report covers a study conducted at the Aircraft Porous Media, Incorporated. Pall Corporation, Glen Cove, L. I., New York (11542), under Air Force Contract AF33(615)-3862. The work was performed in support of Project 6373, "Equipment for Life Support in Aerospace," and Task 637304, "Waste Recovery and Utilization," for the Aerospace Medical Research Laboratories, Aerospace Medical Division, Wright-Patterson AFB, Ohio (45433). Albert B. Hearld, Biomedical Laboratory, was the contract monitor for the Aerospace Medical Research Laboratories. The research was initiated in April 1966 and completed in July 1967.

The principal investigator for the project was Klaus Feindler who was under the direction of Dr. David Pall and Mr. Sid Krakauer, both of whom contributed invaluable technical assistance, as did Mr. R. Fonte, who carried out the testing program.

This technical report has been reviewed and is approved.

WAYNE H. MCCANDLESS  
Technical Director  
Biomedical Laboratory  
Aerospace Medical Research Laboratories

# ABSTRACT

A study was conducted to provide design criteria for a system employing multifiltration for reclaiming bacteria-free potable water from wash water, dehumidification water, and water recovered from urine. Based on the design criteria developed, a laboratory model was constructed and tested. The laboratory model consisted of a transfer pump, filtration units, a storage tank, and a dispenser. It was designed to process 22 liters of water each day during a 36-day simulated aerospace mission, with no major maintenance, replacement of parts, cleaning, or calibration. Provisions were made for the replacement of expendable parts, when required, in order to operate for 180 days.

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## SECTION I

### INTRODUCTION

For the astronaut in prolonged earth orbit, the need for potable water is second only to the need for breathing oxygen. A crew of four on a 60-day mission would require approximately 29,000 lb of fresh water on the basis of 5.5 liters/man day. Estimations have been made that it takes \$10,000 and 1,000 lb of thrust to launch 1 pound of water plus supporting equipment into earth orbit. Funds to finance the launch are available, but 29 million pounds of thrust are not. Therefore, considerable effort has been expended in designing space water reclamation systems that can recover potable water from waste liquids.

In the space station ecology, man himself "closes the loop." In terms of his metabolic process, the astronaut becomes a producer of water since he excretes more water than he consumes, approximately 0.5 to 0.7 lb/man day. In view of the gas leakage expected from a space station, water reclamation takes on added importance, since the excess water together with the water exhaled can be electrolyzed by a Sabatier Reactor to produce O<sub>2</sub> and compensate for some of the leakage.

Filtering Systems (hereafter, identified as FS) are ideally suited for water reclamation on board space stations (with resupply) because of:

- high reliability, i.e., with the exception of a pump, it is without moving parts. No maintenance is required except the replacing of spent filter media.
- readily available technology, i.e., no new development effort is required to apply the FS to space station use.
- no energy requirements, i.e., power beyond that for fluid transfer is not required.
- no phase separation is required, thus, the process has inherent zero-gravity capabilities.
- ease of logistics, i.e., the expendables can be resupplied in compact form at 60 to 90-day intervals, thus handling and storage are simplified.
- emergency characteristics, i.e., in case of a power failure, or a failure of the urine reclamation loop, the FS can be operated (water expulsion by hand or by gas) with no loss in the quality of the water.



- . flexibility, i.e., it can take on overloads without penalty should onboard requirements change.
- . water quality is extremely high, approaching that of triple distilled water.
- . active system, i.e., a recirculation loop provides for continuous purification regardless of water consumption.
- . simple capacity determination by observation through clear plastic tower.
- . FS can be tailored to give optimum removal of particulate contamination, e.g., trace elements discharged from a Sabieter Reactor; metals from the heat transfer surface, pump, seals, etc.
- . practically negligible fixed weight, considering the reclamation by itself.
- . instant startup and shutdown, i.e., no time is required to achieve operating temperature and pressure, etc.
- . high recovery efficiency, i.e., only a minor amount of water is lost for or during running of system.
- . no buildup of noncondensibles with resultant vent losses.
- . location adaptability, i.e., the FS can be placed in any convenient location inside a space vehicle.

A shortcoming of the FS is that it cannot be economically used to recover water from urine. Urine, because of its much higher solids content, requires much larger beds of adsorbents and ion exchange materials, an excessive weight penalty. A simple and economical method for regenerating the materials may alter this facet.

Development of the FS cannot be divorced from the problems of: (1) standards for both space water reclamation apparatus and space water quality, (2) determination of contamination in quality and quantity in terms of the origin of the various waste waters, and (3) the design of representative test water and test methods. The AMRL\* has done work in this area, and prepared a number of publications (ref 1), including the proposed space water standard presented to the Aerospace Medical Association (ref 2). Similar standards have been advanced by Douglas Aircraft (ref 3 and 4).

\*Aerospace Medical Research Laboratories, Wright-Patterson AFB, Ohio

A number of FS's have been built (ref 5,6,7 and 8), but because of the above mentioned problems, little analytical knowledge is available that would have a direct application to FS's in space stations or similar vehicles.

From a study of the many reports published on water reclamation systems, none of the current water reclamation systems can meet the proposed standards without some form of additional treatment, be it pretreatment or posttreatment or both. Posttreatment is usually recommended, either by a separate device, such as FS, catalytic burner, and sterilizers, or by integral applications of adsorbent catalysts, bactericides, etc. Failures in the area of organic removal, as well as sterilization, are also noted. Thus, the evaluation of competitive approaches becomes extremely difficult. Very rarely are contamination loads analyzed in terms of quantity and quality, and then compared with a matching analysis of product water that has had primary and secondary treatment. More often, bacterial loading is unrealistic. Positive agreement on loading standards will do much to alleviate this situation.

There is great need for "space" water to be free from both viable and nonviable organisms, as has been documented by C. Metzger, Dr. A. Slonin, Dr. S. London, and others (ref 1 and 2). Either filtration or catalytic oxidation can accomplish this goal, with filtration having a greater reliability in the event of a temporary shutdown because of a power failure, a maintenance need, flooding of the catalytic burner, or a comparable problem. Even with a catalytic burner, a filter may be required downstream to remove nongaseous products of combustion, e.g., carbon.

## SECTION II

### SYSTEM DESIGN

#### General

A schematic of the FS is shown in Figure 1.

Recovered water to be processed is introduced into the FS via an inlet strainer into the water side of a tandem pump. Discharged at approximately 20 psig of pressure, the water enters an inlet filter where prefiltration and odor removal takes place. This effluent is demineralized and decolorized in an ion exchange tower and stored in a reservoir from where, upon demand, it is drawn through after-filters for bacteria removal by cold sterilization. The after-filters also reject any particulate matter which may have been released from the tower packing into the effluent stream. Potable water is available from a dispenser.

A feedback loop in the FS permits a portion of the processed water to return from the reservoir to the pump inlet. The amount returned is metered by a capillary tube. The feedback loop prevents stagnation inside the reservoir and provides optimum purity of the water by recirculating it through the inlet filters and ion exchange tower. It also provides relief for the pump, preventing overloading and assuring a continuing supply of water to the pump.

#### Description of Components

##### Inlet Strainers

The inlet strainer (Figure 2, View BB) contains a RIGIMESH® woven wire mesh medium to provide 74 $\mu$  filtration. This filter protects the pump against large particles with abrasive or clogging capabilities, such as metal chips, skin, hair, and other debris which might be released from the external collection system. The strainer can readily be removed for cleaning and thus has an indefinite service life. All materials are stainless steel. The dirt capacity is sufficiently large to last at least 36 days without cleaning.

##### Pump

The pump (see Figure 2, View BB) has two stainless steel pistons tied together by a yoke. A stepping-type motor engages through a ratchet device, the yoke changing rotary motion into reciprocating motion. For the water piston, there are two sets of seal rings.

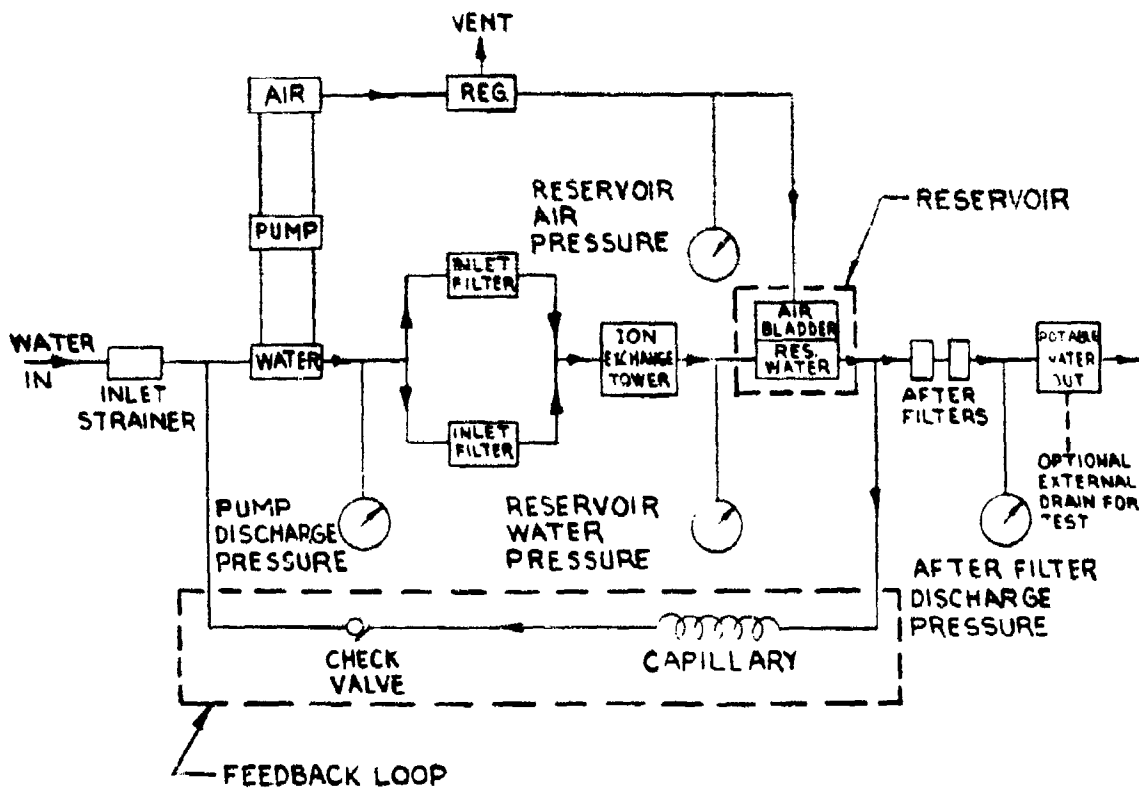


Figure 1. Filtering System

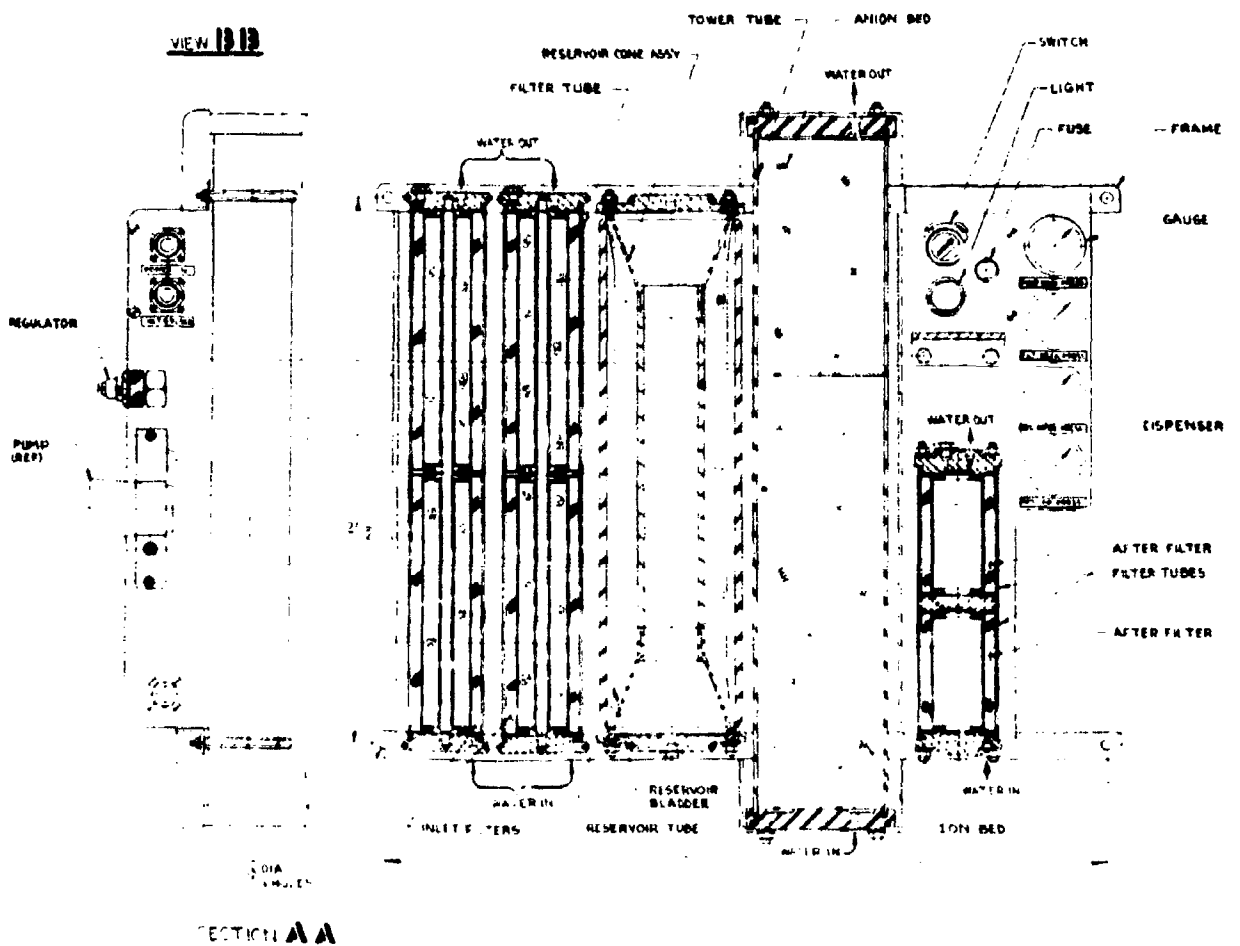
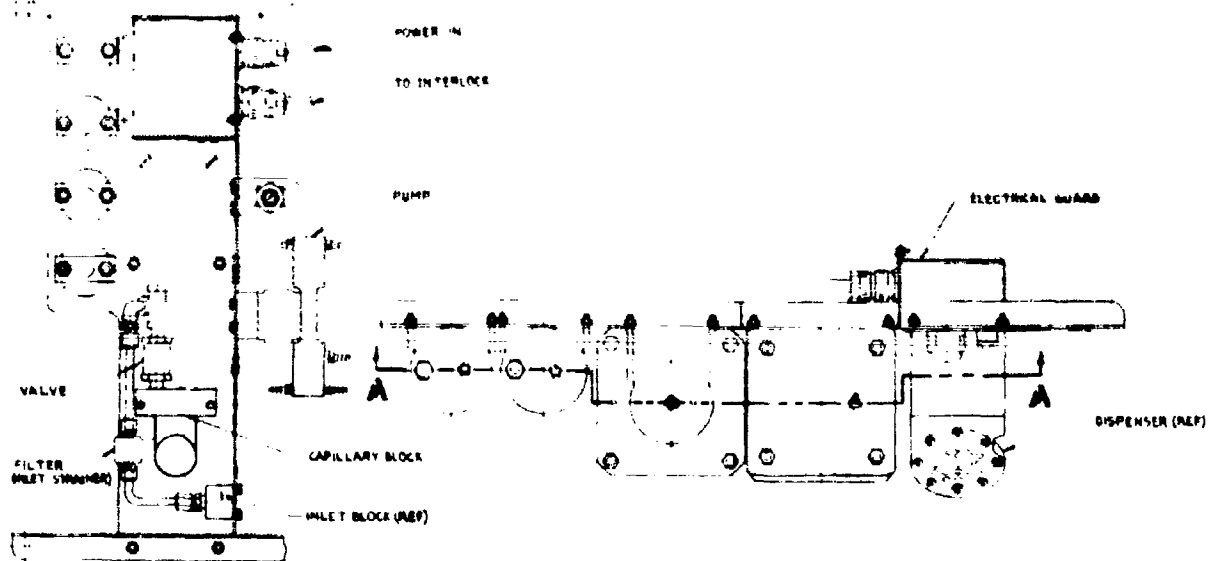


FIGURE 2. FILTER SYSTEM

**D**

**Figure 1**

1

1

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Made of Teflon, these seal rings combine good lubricity with low friction. For zero leakage, a feedback path is provided from between the two sets of seal rings to the inlet of the pump. Both the water and air heads have check valves to prevent back flow. Water delivery is rated at 30 ML/MIN. The pump motor is designed to dissipate heat rapidly, and can stall indefinitely without harm. It consumes 6 watts and operates from a 115-volt, 60-cycle power source.

#### Regulator

During the operating cycle, air is drawn into one side of the tandem pump and discharged at 30 ML/MIN via a regulator (see Figure 2, View AA), which is set to deliver 15 psig to the reservoir. The air inflates the bladder inside the reservoir forcing the water toward the outlet of the reservoir. The regulator maintains full control over the bladder pressure by either feeding air to the reservoir or venting excess air to the ambient.

#### Inlet Filter

The inlet filter (see Figure 3) consists of two filter assemblies in parallel with two cartridges each. The filter medium, ULTIPOR<sup>®</sup>.1, provides 0.12 $\mu$  nominal and 0.35 $\mu$  absolute filtration in water service. The filter will remove all particulate contaminants and prevent fouling of the ion exchange bed further downstream, thus preserving valuable capacity. By removing bacteria, the load on the downstream filter will be reduced and bacteria growth minimized, if not eliminated. The filter elements combined will provide about 32 square feet of filter area, which, according to experiments and estimates, should amply cover a 36-day interval. The filter elements are of the disposable type. The entire filter assembly can be removed by loosening the U-bolts at the lower and upper rails. Water flow and air entry can be blocked by putting hose clamps on the inlet and outlet tubing. After the tubing is disconnected beyond the clamps, the assembly can be moved forward and replaced by a new sterilized assembly.

A special vent plug is provided in the top of each filter to permit priming. The space inside each filter element is filled with Type PK activated charcoal, manufactured by Barnebey-Cheney, Columbus, Ohio, for odor removal, particularly of organic substances. The charcoal is retained by a perforated disc at each end of the element.

#### Ion Exchange Tower

Water, free of solids and bacteria, enters the tower at the bottom and passes upward through a coarse strainer and cushion into a bed of PALL MIX I, a mixed ion exchange resin. The water passes on through a thin perforated separator into a bed of anion exchange resin,



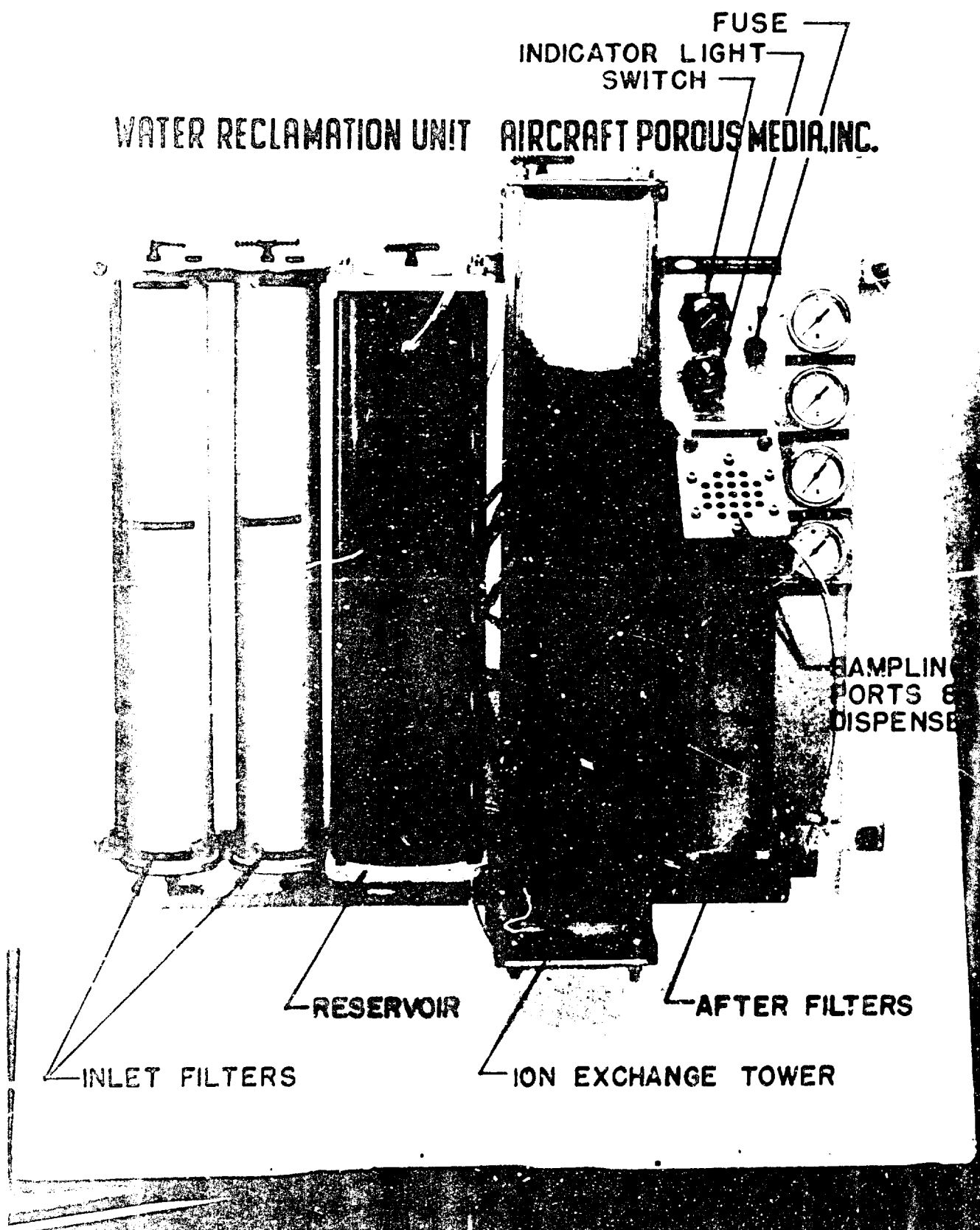


FIGURE 3. Filtering System - Front View

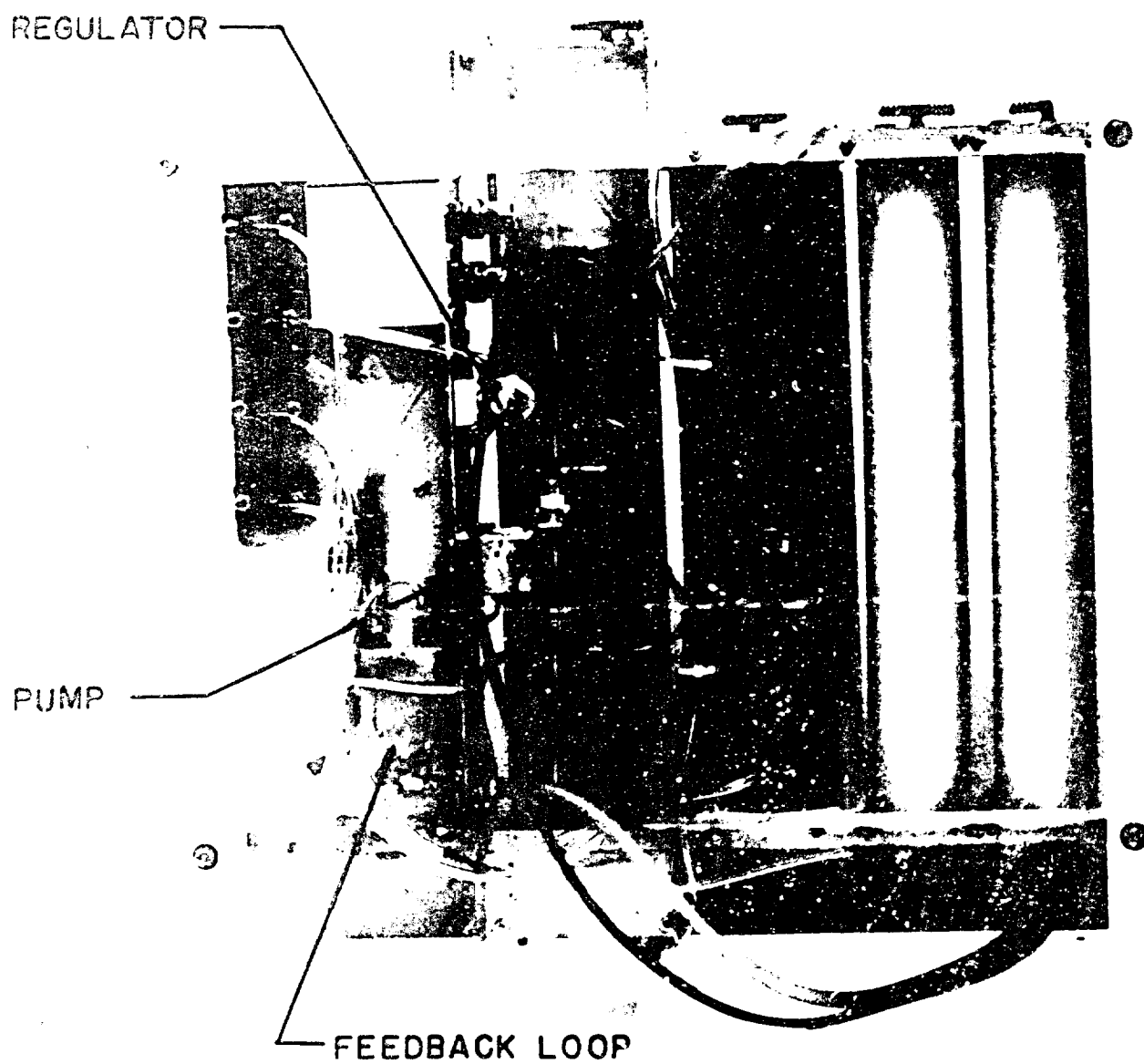


FIGURE 4. Filtration System - Rear View

then exits through a coarse strainer and cushion at the top of the tower. The bulk of demineralization takes place in the PALL MIX I, and it is the purpose of the anion exchange to make final pH adjustments. The strainers and cushions keep the resin bed contained by light axial loading and prevent resin leakage. The cylindrical section of the tower is made of clear plastic to permit observation of the ion exchange resin. As the resin is exhausted (used up) there is a distinct color change that can be observed beginning at the bottom of the tower and progressing upward.

The need for replacing the ion exchange resin can be readily determined by: observing the color change in the resin column, or measuring the specific conductivity of the effluent. Discoloration of the resin from inlet to the outlet or a conductivity in excess of 500µmho/cm is a criterion for replacement.

The bed capacity is sufficient to purify influent waters with contamination loads that have been estimated for a 4-man 36-day simulated aerospace mission. After bed exhaustion, the entire assembly can be removed and exchanged in a fashion similar to that described for the inlet filter.

#### After Filter

The after filter contains two filter elements of the disposable type with a 0.12/0.35µ rating and arranged in series. Like the inlet filter, the medium is ULTIPOR®.1. The ion exchange beds are expected to be inert to abrasion and growth. However, any solids or bacteria generated there are removed by the after filter, allowing only pure and sterile water to flow into the dispenser. A vent plug is provided at the top. This filter is sterilized prior to assembly, and should be assembled under sterile conditions.

Replacement can be accomplished by the same method suggested for the inlet filter.

#### Reservoir

The reservoir (see Figure 3) consists of a transparent cylinder which can hold 4 liters of potable water and 2 liters of compressed air. Inside, extending over the length of the cylinder, are a cone assembly (see Figure 2, Sec AA) and a bladder (see Figure 2, Sec AA). Between the bladder and cylinder wall is a liner of woven stainless steel mesh. Holes in the cone permit compressed air to inflate the bladder which is sealed to the reservoir end caps together with the cone. The cone prevents a complete collapse of the bag, which could

block the air inlet. It also assures uniform contact of the bladder with the water. The bladder, by means of the air pressure inside, exerts a force on the water causing it to occupy all available space between the bladder and cylinder wall as well as throughout the FS. This method of containing the water is necessary for the proper operation of the FS in a weightless environment. The stainless steel mesh maintains positive separation of bladder and cylinder at all times, and prevents blocking of water flow and outlets by the bladder.

#### **Electrical Parts**

The electrical parts of the FS are shown in Figure 5.

With the fuse in, switching the power on energizes the pump motor and lights the indicator lamp. An electrical interlock (see Figure 2, View AB) on the side panel is in series with the power switch. It allows remote control of the FS, e.g., by a computer, or simply by a liquid level control in the collection system. The power for operating the FS is fed through a connector on the side panel.

#### **Miscellaneous Parts**

Gauges to show pump, filter, reservoir water, and air pressures are provided. Tygon and stainless steel tubing is used to connect the various components, and a check valve (see Figure 2, View AB) controls the direction of flow through the feedback loop. Water is brought into the system through an inlet block (see Figure 2, View BB) in the side panel. It is dispensed through a special fitting which has a self-sealing rubber membrane and is located on the front panel (see Figure 3). A protective cover saturated with a disinfectant is snapped around this fitting. When a sample of the water is drawn for microbiological testing, the cover is lifted and a hypodermic needle of a sterilized syringe is pushed through the membrane with its piston in the forward position. Potable water will then automatically be forced into the syringe by the pressure inside the system.

#### **Operation**

The Filtration System is operated in the following sequence: priming, charging, acquiescence, and discharging.

##### **Priming**

After component sterilization and assembly, the unit is connected to a supply of distilled water, or to a waste water collection system. While it is not necessary to use distilled water for priming, the use of such water will greatly accelerate the rate at which the effluent will drop to the lowest possible contamination level. Priming is

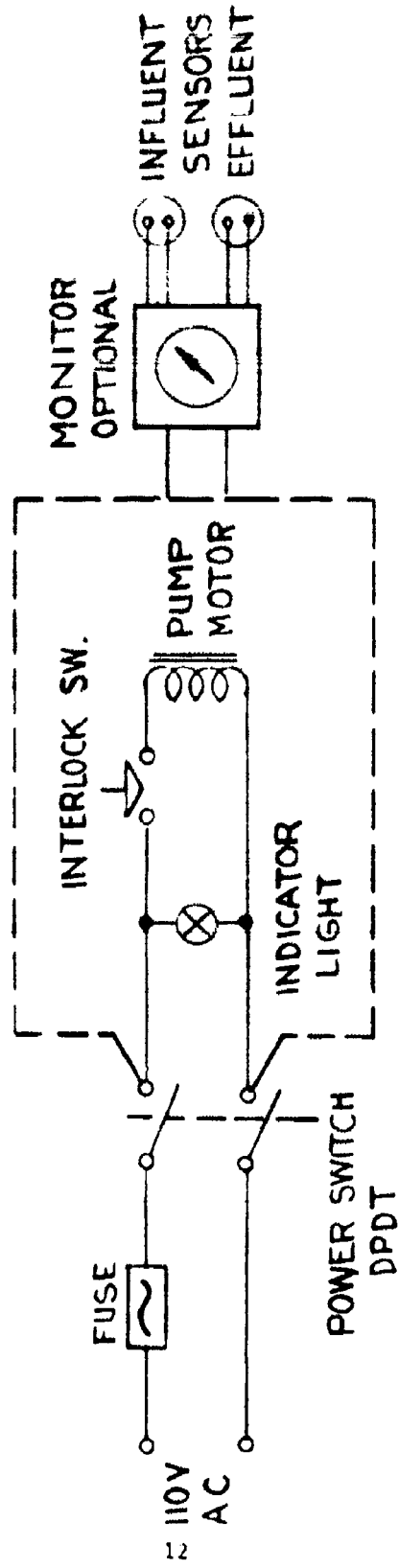


Figure 5. Electrical Schematic

continued with all vents open until all entrapped air is expelled from the system. While water priming is in progress, air is pumped into the reservoir to inflate the bladder inside the reservoir. Most desirable is the mode where the bladder is completely inflated before water begins to enter the reservoir. An easy way to accelerate this process is to provide a valve that is connected to an external source of compressed air (bicycle pump, gas bottle, etc.)

#### Charging

With all vents closed, water enters the reservoir and displaces some of the air inside the bladder by forcing it against the cone assembly (see Figure 2, Sec AA) that extends the length of the reservoir. Charging is complete when approximately 4 liters of water are holding the bladder against its restraint with approximately 2 liters of air at 15 psig remaining inside the bladder.

Pressure conditions in the reservoir are indicative of the following conditions:

|         |   |                                      |
|---------|---|--------------------------------------|
| P Water | < | P Air - Reservoir empty              |
| P Water | ≈ | P Air - Reservoir loading            |
| P Water | > | P Air - Reservoir filled to capacity |

#### Acquiescence

All additional water pumped into the reservoir after it is charged is returned to the pump via the feedback loop, to provide continuous recirculation through the inlet filters, the ion exchange tower, and the reservoir.

#### Discharging

When water is dispensed through the potable water outlet faster than the pump can supply, the bladder displaces the water in the reservoir until the entire storage volume is discharged. Beyond this point, the water discharged will equal the water pumped. In case of power failure, the 15 psig air pressure inside the bladder will discharge up to 4 liters of stored water through the dispenser.

I anticipate that the unit will operate most of the time in the charging and discharging condition. Methods for sterilizing the FS prior to its being put into use are described in Appendix I.

#### Configuration

The complete system, less water, weighs approximately 50 pounds and has a displacement volume of approximately 1500 cubic inches. It occupies less than one half of the 27-inch wide by 27-inch deep by 31-inch high space into which it was required to fit. It was, however, designed to be mounted between uprights on 27-inch centers.

Sizeable weight and volume reductions (see Alternates) can be made in the FS. For reasons of simplicity and expediency, no concentrated efforts were made to accomplish the reductions.

Controls are located on the front for easy operation and surveillance. All components to be serviced can be reached from the front. Power, interlock, and feed water connections can be made by reaching over or below the front panel.

#### Capacity

The FS can continuously produce potable water at a rate of 15 ML/MIN with influent water conforming to the specifications shown in Appendix II.

#### Materials

All materials of construction are inert and nontoxic. Special care was taken to avoid the formation of electrolytic couples. Direct contact between stainless steel and aluminum, for instances was avoided. The major construction material is Series 6061 aluminum.

#### Alternates

The use of four filter cartridges is based on conservative estimates. Under actual service conditions, it may be unnecessary to provide such a large filter area, and one of the two filter assemblies could be eliminated. It is also possible to design a special filter element that would necessitate only a single housing and thus lead to reductions in volume and weight. This is an improvement to be considered for future designs.

By means of a bypass, all or any portion of the influent flow can be made to bypass the ion exchange tower and flow directly to the entrance port of the after filter. Such an arrangement will meet specification requirements and will extend the life of the ion exchange beds. Substantial savings in volume and weight will result, since water of an acceptable ion content could be bypassed and less ion exchange material would be required.

It may be desirable to incorporate a purity monitor into future designs. Miniature cells for sensing specific conductivity can be installed to control a bypass as well as the quality of the effluent water. It has been demonstrated that specific conductivity is the major parameter reflecting water quality and can be measured with a minimum of instrumentation. Readout could be accomplished via a compact conductivity bridge.

Automatic control is possible by using a miniature analog computer in conjunction with a mixing valve.

The mixing valve could be set manually, or be driven continuously by a computer output signal to suit water output to individual tastes and yet retain maximum capacity.

A urine processing unit with a vapor filtration step between vaporizer and condenser can be added to the back of the FS without an increase in the overall envelope. PALLFLEX® materials have been tested for this application, i.e., vapor filtering. Compact heat exchangers and refrigeration machinery are also available for use in vapor filtering units.



## SECTION III

### SYSTEM EVALUATION

In many respects the test of the FS was conducted under conditions more severe than those stipulated in the work statement. It was believed that by running at maximum flow rate, rather than at rated flow, more meaningful test data could be obtained and would lead to increased confidence in the FS. The following conditions increased the severity of the testing:

- (1) Test duration was 6 days instead of 5.
- (2) Flow rate averaged 27.4 ML/MIN instead of 15.0 ML/MIN.
- (3) Process volume was 233 liters instead of 130 liters.
- (4) Part of the capacity of the ion exchange tower was exhausted during previous test work.
- (5) Multiple passes through the feedback loop which tends to "over purify" the water were not permitted.

It is evident from the above that contact time of the raw water with the filter and ion exchange media was sharply reduced, emphasizing that the FS meets specification requirements even at maximum flow. The increased flow rate allowed the bladder inside the reservoir to be stressed more rigorously, both in length of travel and frequency of movement. Prior testing and accelerated flows shifted the ion exchange tower the closer toward bed exhaustion. This is especially important should the contamination levels rise as a function of accumulated process volume.

The results of the tests were:

- (1) The bag was fully exercised about 90 times; its performance was flawless (no hanging, blocking or tearing was observed).
- (2) Purified water was dispensed at the rate of 100 to 250 ML/MIN, and in volumes of 1,500 to 3,500 ML, depending on the opening of sampling valve.
- (3) In spite of an 83% reduction in contact time, all effluent was within allowable limits (see Table 1), thus lending weight to the feasibility of a bypass (see Alternates, Section II).

- (4) The pressure drops observed were negligible for the entire system.
- (5) Sterilization of the ion exchange tower was initially incomplete, or did not endure.
- (6) Sterilization of the reservoir was initially incomplete, or did not endure.
- (7) Bacteria are believed to have propagated upstream in the liquid-solid interface, i.e., the tubing wall, to give a positive count at the inlet filter outlet at the third day.
- (8) The results of the analysis of the effluent from the FS with the test solution (Appendix II) as the input are given in Table 1. The effluent was within allowable limits each day of a 6-day test.
- (9) Microbiological data obtained each day from selected points in the FS are shown in Table 2. The effluent was free of bacteria although the input was highly contaminated. Samples (100 ml each) were taken twice daily for the testing.
- (10) The relationship between pH, conductivity, and the volume of water pumped through the ion exchange tower is shown in Figure 6.

TABLE I

## Test Results

## Filtration System Effluent

| TEST                 | UNITS            | ALLOWABLE LIMITS | 1st Day |      | 2nd Day |      | 3rd Day |     | 4th Day |     | 5th Day |     | 6th Day |    |
|----------------------|------------------|------------------|---------|------|---------|------|---------|-----|---------|-----|---------|-----|---------|----|
|                      |                  |                  | AM      | PM   | AM      | PM   | AM      | PM  | AM      | PM  | AM      | PM  | AM      | PM |
| Specific conductance | umho/cm          | 500 max.         | 12      | 7    | 4       | 5    | 3       | 4   | 3.5     | 7   | 4       | 4   | 3.5     |    |
| pH                   | /                | 5.5 to 9.0       | 6.4     | 6.4  | 6.4     | 6.2  | 6.1     | 6.1 | 6.0     | 6.6 | 6.6     | 6.7 | 6.6     |    |
| Color                | Chloro-platinate | 15 max.          | (2)     | <1   | <1      | <1   | <1      | <1  | 1       | <1  | <1      | <1  | <1      |    |
| Turbidity            | Jackson          | 25 max.          | (2)     | <1   | <1      | <1   | <1      | <1  | <1      | <1  | <1      | 1   | <1      |    |
| Organics (COD)       | mg/liter         | 100 max.         | 100     | 91   | 34      | 77   | 28      | 66  | 66      | 44  | 15      | 10  | 12      |    |
| Bacteria (3)         | organisms/100 ml | 0 max.           | 0       | 0    | 0       | 0    | 0       | 0   | 0       | 0   | 0       | 0   | 0       |    |
| Volume Processed     | Liters           | N/A              | 38.9    | 50.3 | 77.8    | 89.1 | 117     | 128 | 155     | 167 | 194     | 206 | 234     |    |
| Used-up Capacity (4) | %                | N/A              | 5       | 6    | 10      | 11   | 15      | 16  | 20      | 21  | 25      | 26  | 30      |    |

NOTES: (1) Day after start of test.

(2) On the colorimeter scale 1% of deflection corresponds to approx. 1 unit. Since no deflection could be observed this was interpreted to mean "1".

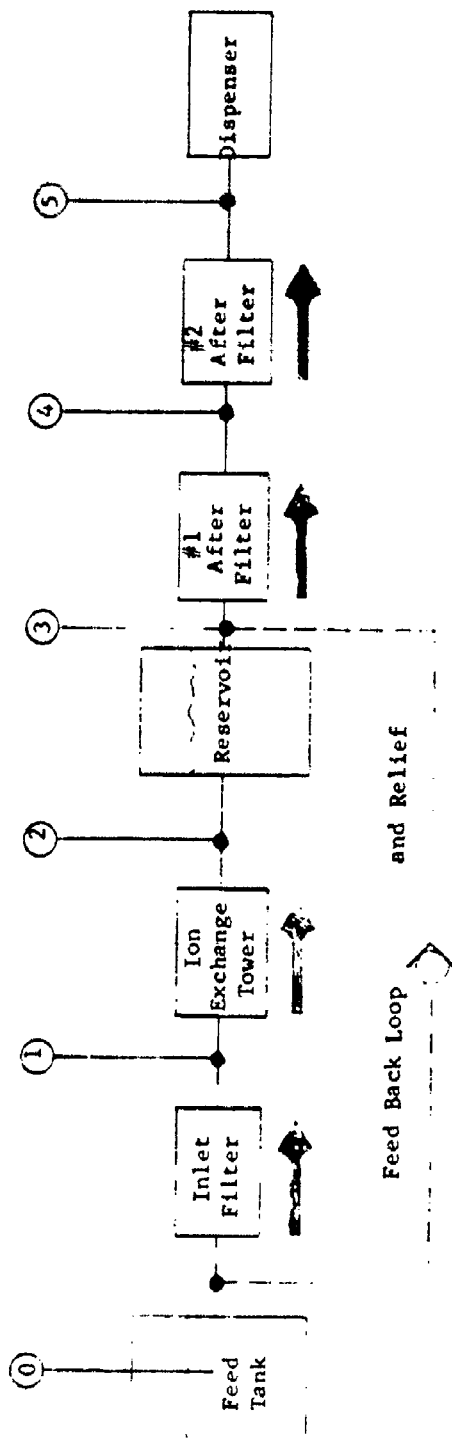
(3) The bacteria count is a summary from Table 2 - Points #4 and #5.

(4) The capacity is related to design capacity. Considering the margin of safety used, actual capacity may be higher.

TABLE II

## Microbiological Data

## Filtration System Effluent



## BACTERIA CONCENTRATION per 100 ml

| Days After Start | Point # 0  | Point # 1 | Point # 2 | Point # 3 | Point # 4 | Point # 5 |
|------------------|------------|-----------|-----------|-----------|-----------|-----------|
| 1st Day          | 45,000,000 | 0         | >12,000   | >12,000   | 0         | 0         |
| 2nd Day          |            | 0         | 810       | 2,000     | 0         | 0         |
| 3rd Day          |            | 570       | 1,170     | >12,000   | 0         | 0         |
| 4th Day          |            | >12,000   | >12,000   | >12,000   | 0         | 0         |
| 5th Day          |            | >12,000   | >12,000   | >12,000   | 0         | 0         |
| 6th Day          | 91,000,000 | >12,000   | >12,000   | >12,000   | 0         | 0         |

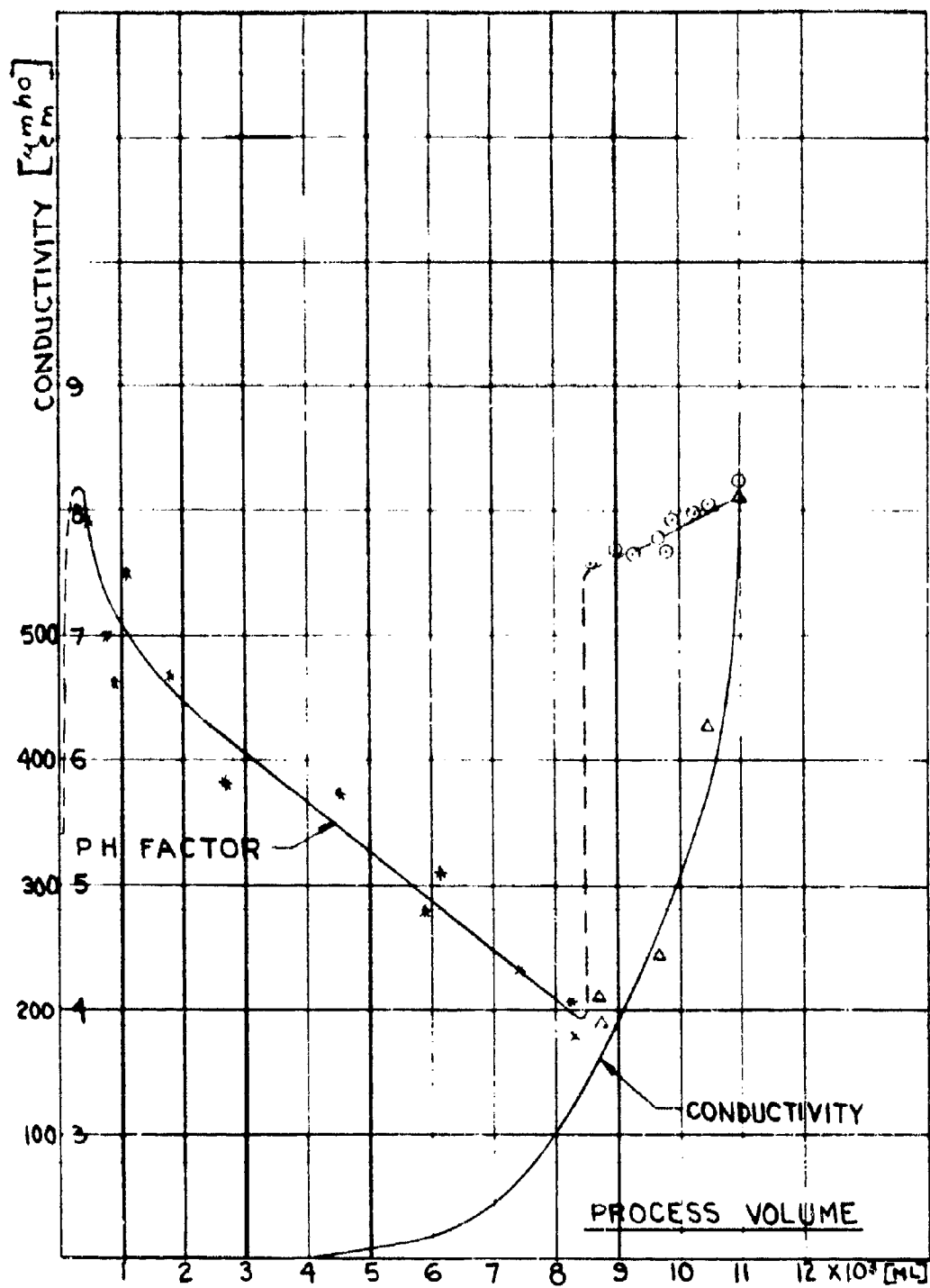


Figure 6. Tower Test # 1

## SECTION IV

### RECOMMENDATIONS

Additional test work is recommended in the following areas:

- (1) Pinpoint system sterilization problems. Determine:
  - a. origin of contaminating bacteria
  - b. if propagation can be carried on in an active system against the direction of flow
  - c. most effective method to sterilize the ion exchange beds without loss in purification capacity
- (2) Determine the quality of effluent at rated average flow, and see if there is an improvement over the excellent effluent obtained at increased flow.
- (3) Conduct a life test of the ion exchange resins using 792 liters of test fluid. During this test, observe the movement of the discoloration front in the ion exchange tower. Plot this movement as a function of process volume, and correlate with pH and conductivity measurements. Such data will permit a quick and convenient check of the ion exchange tower for on-board maintenance.

## APPENDIX I

### Sterilizing the Filtration System

During testing, difficulties were encountered with the sterilization of the ion exchange tower. From the limited information available (ref 9, 10 and 11), ion exchange resins permit or support bacterial growth, or both. Autoclaving was not tried because it was thought that this would impair the capacity of the resin to demineralize, and also, the assembly included thermolabile materials that do not permit excessive heating. Sterilization of the ion exchange tower can be accomplished in situ by modifying the piping diagram (see Figure 7) and flushing with a combination of ethylene oxide and formaldehyde.

The remainder of the FS assembly can be sterilized with a combination of ethylene oxide and formaldehyde after the piping network has been modified. This modified network provides for the simultaneous application of the formaldehyde to the ion exchange tower and the ethylene oxide to the balance of the system. The purpose of the formaldehyde is to, at least temporarily, sterilize the ion exchange tower until the FS is turned on and decontaminated water begins to circulate.

#### Procedure

Add tubing and valves 1,2,3,4 & 5, as shown in Figure 7, then operate in the following sequence:

- a) Shut valves (1) and (2), then open valves (3), (4) and (5). NOTE: Opening valves (4) and (5) will allow ion tower to drain.
- b) Connect a pressure regulated supply of ethylene oxide immediately upstream of the inlet filters at point (A) - this is accomplished by removing existing tubing from the fitting and replacing it with tubing from the ethylene oxide supply.
- c) Disconnect the tubing from the fitting located in the base of the sampler which is directly downstream of the after filters.
- d) Increase the supply pressure from the ethylene oxide from 0 to 5 psi, and maintain that pressure for 5 minutes, or until the ethylene oxide is exiting from the disconnected fitting in the base of the sampler.

- e) Reduce pressure to 1 psi and reconnect the tubing (disconnected in sequence (c)) to the fitting located in the base of the sampler.
- f) Increase the supply pressure from the ethylene oxide from 1 psi to 15 psi, and maintain this pressure.
- g) Valves (4) and (5) previously opened in sequence (a)) are to remain open until all water in the ion exchange tower has drained.
- h) Connect a supply of 0.5% formaldehyde (USP) to valve (4) at base of tower, and fill the ion exchange tower. To ensure that residual water in the tower does not dilute the formaldehyde solution, continue filling until 1 to 2 liters overflows at valve (5).
- i) Close valves (4) and (5) and let stand for 8 to 12 hours.
- j) Open valves (4) and (5) and allow ion exchange tower to drain.
- k) Connect a source of sterile, deionized water to valve (4) and flush a minimum of 50 gallons through the ion exchange tower.
- l) Close valves (4) and (5).
- m) Reduce the supply pressure (ref sequence (f)) to 0 psi and allow the system pressure to return to zero.
- n) Disconnect the ethylene oxide supply (ref sequence (b)) and reconnect tubing disconnected during sequence (b)).
- o) Close valve (3) and open valves (1) and (2).



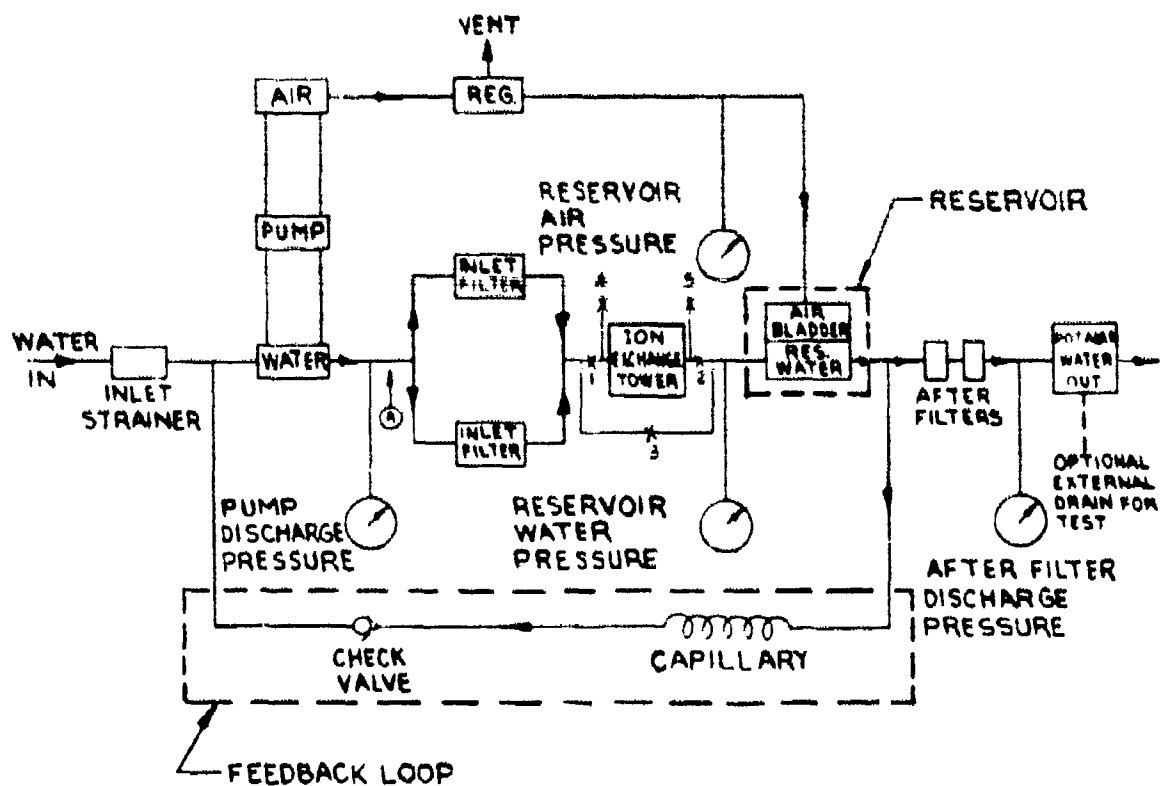


Figure 7. Sterilization Schematic

## APPENDIX II

### Test Water Specifications

#### A - TEST SOLUTION

The test solution was made up in five 22-liter lots. For each, 14 liters of Solution A were mixed with 8 liters of Solution B and the chemical oxygen demand (COD) of the mixture adjusted to 5000 mg/liter. The COD was adjusted to 5000 mg/liter by adding a graphite suspension which contained 22% carbon by weight. Bacteria were added to give  $1 \times 10^6$ /ml. Each lot was stored in a clean 6 gallon polyethylene carboy. Solutions A and B were compounded as follows:

#### SOLUTION A

1. The following chemicals\* were added, in micrograms/liter, to 14 liters of deionized water:

|   |        |   |         |
|---|--------|---|---------|
| Zn Cl <sub>2</sub>                              | 10,400 | K <sub>2</sub> Cr O <sub>4</sub>                    | 124     |
| Cd Cl <sub>2</sub>                              | 34     | V SO <sub>4</sub>                                   | 32      |
| Fe Cl <sub>3</sub>                              | 890    | Ba Cl <sub>2</sub>                                  | 1.514   |
| Na <sub>2</sub> Mo O <sub>4</sub>               | 42     | Sr Cl <sub>2</sub>                                  | 18      |
| Mn Cl <sub>2</sub>                              | 150    | Hg (NO <sub>3</sub> ) <sub>2</sub> H <sub>2</sub> O | 200     |
| Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> | 3,170  | Ca Cl <sub>2</sub>                                  | 27,700  |
| Cu SO <sub>4</sub>                              | 2,510  | Mg Cl <sub>2</sub>                                  | 19,600  |
| Ag NO <sub>3</sub>                              | 79     | Na Cl   | 151,500 |
| Ni SO <sub>4</sub>                              | 32     | K Cl  | 76,200  |
| Co SO <sub>4</sub>                              | 53     | As Cl <sub>3</sub>                                  | 125     |
| Pb (NO <sub>3</sub> ) <sub>2</sub>              | 80     | (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>     | 338,000 |
|   |        | NH <sub>4</sub> Cl                                  | 44,000  |

Sod borate                      As required to provide  
150 mg of Boron

Sod phosphate                  As required to provide  
500 mg of Phosphorus

Urea                              350,000

2. Yellow dye was added to bring the color up to 30 to 40 chlor-platenate units. (Any convenient dye can be used.)

\*Where applicable, the amounts used were increased to allow for water of hydration.

3. Na OH or H Cl was added as required to adjust to pH - 7.
4. Na Cl was added, if needed, to obtain an electrical conductivity of not less than 700 mic mhos/cm.
5. The pH was readjusted to 7.0 with Na OH.

#### SOLUTION B

Solution B was a 0.05% solution of Benzalkonium chloride.

The 5 lots of test solution (110 liters) were mixed together in one lot and then stored in a special container which allowed refrigeration (40°F constant), as well as continuous agitation. One 100 ml sample was drawn each day from the container and influent bacterial levels were verified by bacterial count.

#### B - TEST SOLUTION - Analytical Standards

| <u>Trace Elements</u> | <u>µg/l</u> | <u>Cations</u>                     | <u>µg/l</u> |
|-----------------------|-------------|------------------------------------|-------------|
| Zinc                  | 5000        | Calcium (Ca)                       | 10          |
| Cadmium               | 20          | Magnesium (Mg)                     | 5           |
| Boron                 | 150         | Sodium (Na)                        | 60          |
| Phosphorous           | 500         | Potassium (K)                      | 40          |
| Iron                  | 300         | Arsenic (As)                       | 0.5         |
| Molybdenum            | 20          | Ammonia (NH <sub>3</sub> /N)       | 100         |
| Manganese             | 50          |                                    |             |
| Aluminum              | 500         |                                    |             |
| Beryllium             | < .03       | <u>Anions</u>                      | <u>µg/l</u> |
| Copper                | 1000        | Sulfate (SO <sub>4</sub> )         | 250         |
| Silver                | 50          | Chloride (Cl)                      | 250         |
| Nickel                | 12          | Nitrate (NO <sub>3</sub> /N)       | 45          |
| Cobalt                | 20          | Total Phosphate (PO <sub>4</sub> ) | 10          |
| Lead                  | 50          |                                    |             |
| Chromium              | 50          |                                    |             |
| Vanadium              | 10          |                                    |             |
| Barium                | 1000        |                                    |             |
| Strontium             | 10          |                                    |             |
| Mercury               | 120         |                                    |             |

Other Tests

|                                      |                           |
|--------------------------------------|---------------------------|
| pH (Units)                           | 7                         |
| Conductivity ( $\mu$ mhos/cm)        | 700                       |
| Turbidity (Jackson Units)            | > 25                      |
| Color (Chloroplatinate Units)        | > 15                      |
| Odor                                 | > 3                       |
| Total Hardness ( $\text{CaCO}_3$ )   | 160 mg/l                  |
| Total Alkalinity ( $\text{CaCO}_3$ ) | 200 mg/l                  |
| Total Solids                         | > 500 mg/l                |
| Chem $\text{O}_2$ Demand             | 5000 mg/l                 |
| Urea                                 | 350 mg/l                  |
| Total Carbon                         | 1700 mg/l                 |
| Bacteria (As Noted)                  | $1 \times 10^6/\text{ml}$ |

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Security Classification

## DOCUMENT CONTROL DATA - R &amp; D

Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified

|  |   |  |
|--|---|--|
| 1. ORIGINATING ACTIVITY (Corporate author)<br>Aircraft Porous Media, Incorporated<br>Pall Corporation<br>Glen Cove, L.I., New York 11542   |   | 2a. REPORT SECURITY CLASSIFICATION<br>UNCLASSIFIED |
|  |   | 2b. GROUP<br>N/A                                   |
| 3. REPORT TITLE<br><br>FILTERING SYSTEM FOR AEROSPACE WATER RECLAMATION  |   |  |
| 4. DESCRIPTIVE NOTES (Type of report and inclusive dates)<br>Final Report, April 1966 - July 1967  |   |  |
| 5. AUTHOR(S) (First name, middle initial, last name)<br>Klaus Feindler   |   |  |
| 6. REPORT DATE<br>December 1967  | 7a. TOTAL NO OF PAGES<br>31   | 7b. NO OF REFS 11 Refs.<br>32 Bib. Citations       |
| 8a. CONTRACT OR GRANT NO<br>AF 33(615)-3862  | 8b. ORIGINATOR'S REPORT NUMBER(S)   |  |
| a. PROJECT NO 6373<br>c. Task No. 637304<br>d.   | 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)<br>AMRL-TR-67-157   |  |
| 10. DISTRIBUTION STATEMENT<br>Distribution of this document is unlimited. It may be released to the Clearinghouse, Department of Commerce, for sale to the general public.   |   |  |
| 11. SUPPLEMENTARY NOTES  | 12. SPONSORING MILITARY ACTIVITY<br>Aerospace Medical Research Laboratories<br>Aerospace Medical Div., Air Force Systems<br>Command, Wright-Patterson AFB, OH 45433 |  |
| 13. ABSTRACT<br>A study was conducted to provide design criteria for a system employing multifiltration for reclaiming bacteria-free potable water from wash water, dehumidification water, and water recovered from urine. Based on the design criteria developed, a laboratory model was constructed and tested. The laboratory model consisted of a transfer pump, filtration units, a storage tank, and a dispenser. It was designed to process 22 liters of water each day during a 36-day simulated aerospace mission, with no major maintenance, replacement of parts, cleaning, or calibration. Provisions were made for the replacement of expendable parts, when required, in order to operate for 180 days. |   |  |

DD FORM 1473  
1 NOV 65

Security Classification

Security Classification

| 1A | KEY WORDS   | LINK A |    | LINK B |    | LINK C |    |
|----|---|--------|----|--------|----|--------|----|
|    |   | ROLE   | WT | ROLE   | WT | ROLE   | WT |
|    | Life support<br>Water reclamation<br>Filtering system<br>Carbon filter<br>Membrane filter |        |    |        |    |        |    |

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